Attorney's Docket No. 860-011447-US(PAR) / 2002 0779 *PATENT*

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Express Mail No.: EV 327673397 US
Applicant(s): KELLY et al. **Group No.:**
Filed: Herewith **Examiner:**
For: DETERMINING MODE SPECTRA FOR PRINCIPAL STATES OF POLARIZATION

Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

TRANSMITTAL OF CERTIFIED COPY

Attached please find the certified copy of the foreign application from which priority is claimed for this case:

Country	:Europe
Application Number	:02022742.7
Filing Date	:October 11, 2002

WARNING: "When a document that is required by statute to be certified must be filed, a copy, including a photocopy or facsimile transmission of the certification is not acceptable." 37 CFR 1.4(f) (emphasis added.)

SIGNATURE OF ATTORNEY

Reg. No.: 44,695

Joseph V. Gamberdell, Jr.

Type or print name of attorney

Tel. No.: (203) 259-1800

Perman & Green, LLP

P.O. Address

Customer No.: 2512

425 Post Road,
Fairfield, CT 06824

NOTE: The claim to priority need be in no special form and may be made by the attorney or agent if the foreign application is referred to in the oath or declaration as required by § 1.63.

(Transmittal of Certified Copy [5-4])

Eur päisches Patentamt

Eur pean Patent Office

Office européen des brevets

Bescheinigung

Certificate

Attestation

Die angehefteten Unterlagen stimmen mit der ursprünglich eingereichten Fassung der auf dem nächsten Blatt bezeichneten europäischen Patentanmeldung überein.

The attached documents are exact copies of the European patent application described on the following page, as originally filed.

Les documents fixés à cette attestation sont conformes à la version initialement déposée de la demande de brevet européen spécifiée à la page suivante.

Patentanmeldung Nr. **Patent application No.** **Demande de brevet n°**

02022742.7

Der Präsident des Europäischen Patentamts;
Im Auftrag

For the President of the European Patent Office

Le Président de l'Office européen des brevets
p.o.

R C van Dijk

DEN HAAG, DEN
THE HAGUE, 23/10/02
LA HAYE, LE

EPA/EPO/OEB Form 1014 - 02.91

Europäisches Patentamt | European Patent Office | Office européen des brevets

Blatt 2 der Besch inigung
Sheet 2 of the certificate
Page 2 de l'attestation

Anmeldung Nr.:
Application no.:
Demande n°:
02022742.7

Anmeldetag:
Date of filing:
Date de dépôt:
11/10/02

Anmelder:
Applicant(s):
Demandeur(s):
Agilent Technologies Inc.@a Delaware Corporation
Palo Alto, CA 94306
UNITED STATES OF AMERICA

Bezeichnung der Erfindung:
Title of the invention:
Titre de l'invention:
Determining mode spectra for principal states of polarization

In Anspruch genommene Prioriät(en) / Priority(ies) claimed / Priorité(s) revendiquée(s)

Staat: State: Pays:	Tag: Date: Date:	Aktenzeichen: File no. Numéro de dépôt:

Internationale Patentklassifikation:
International Patent classification:
Classification internationale des brevets:
/

Am Anmeldetag benannte Vertragstaaten:
Contracting states designated at date of filing:
Etats contractants désignés lors du depôt:
AT/BE/CH/CY/DE/DK/ES/FI/FR/GB/GR/IE/IT/LI/LU/MC/NL/PT/SE/TR

Bemerkungen:
Remarks:
Remarques:

Agilent Technologies
Our R f.: 2002-0779

EPO - Munich
3
11. Okt. 2002

October 10, 2002

DETERMINING MODE SPECTRA FOR PRINCIPAL STATES OF POLARIZATION

BACKGROUND OF THE INVENTION

The present invention relates to the determination of an optical property of a device under test in dependence on a spectral parameter for specific polarization states of the incident light which are known as the "principal states of polarization" (PSPs). The invention concerns devices that are used or tested by applying light to the device. The optical property can characterize light that then emerges from the device or characterize another response of the device to the input light, such as an output electrical signal.

In the product note "PDL Measurements using the Agilent 8169A Polarization Controller" by Christian Hentschel and Siegmar Schmidt, it is described how the minimum and maximum insertion loss as well as the polarization dependent loss (PDL) can be obtained by means of the scrambling technique, and by means of the Mueller method that is based on a determination of the Mueller matrix of the device under test (DUT). The document "PDL Measurements using the Agilent 8169A Polarization Controller" is herewith incorporated into the description of the present application and can be accessed via the Internet by means of the URL http://literature.agilent.com/litweb/pdf/5964-9937E.pdf.

SUMMARY OF THE INVENTION

It is an object of the invention to determine the mode spectra of an optical property for the principal states of polarization (PSPs).

The object is solved by the independent claims. Preferred embodiments are shown by the dependent claims.

According to the invention, mode spectra of an optical property for the principal states of polarization of the device under test are determined in dependence on a spectral parameter. The method comprises a first step of determining

polarization effects affect the behaviour of an optical component. The polarization dependent wavelength shift is related to the birefringence of the optical component, which for example may be caused by stress occurring during the manufacturing process, or which may be provided on purpose.

Preferably, the DUT is a planar lightwave circuit (PLC). In this case, the mode spectra obtained for the PSPs of the device under test are the TM (Transverse Magnetic) mode curve and the TE (Transverse Electric) mode curve.

According to a first embodiment of the invention, the minimum and the maximum envelopes are analyzed at spectral points where they are substantially tangent to each other. According to the model underlying the present invention, a partial correspondence of the maximum/minimum envelope values and the mode spectra for the PSPs is assumed. According to this model, the points where the minimum and the maximum envelope touch each other may at the same time be the crossing points of the mode curves for the PSPs. For this reason, these points can e.g. be found by comparing the difference of the minimum and maximum envelope of the optical property with a predefined threshold, whereby said threshold represents the measurement uncertainty. If, for a certain value of the spectral parameter, said difference falls below the threshold, then a crossing point of the PSP mode curves at this value of the spectral parameter is assumed.

In the vicinity of a crossing point, there might exist a range of said spectral parameter where the minimum envelope is very close to the maximum envelope. Instead of identifying one crossing point within this range, an applied algorithm might identify several crossing points. Preferably, in order to assure that only one crossing point is identified, a search window having a certain predefined width is swept over the spectral range of interest. Within said search window, at most one crossing point may be allowed to be assigned. Thus, it is made sure that the crossing points are identified correctly. Said predefined width may be tested or based for example on the polarization dependent

curves for the PSPs are generated. This method is very efficient, because the identification of the crossing points and the construction of the mode spectra is done in one pass.

According to a second preferred embodiment of the invention, the mode curves of said optical property for the PSPs are determined from the transfer matrix of the DUT, based on determining the polarization parameters for the PSPs from this matrix at one or more chosen spectral points of reference. At the PSPs, there is only a weak spectral dependence of the polarization parameters, e.g. the Stokes vector components. Therefore, the polarization parameters can be treated as constants within some spectral range around the points of reference. This means that the spectral dependence of the mode curves for the PSPs is generated by the well-known spectral dependence of transfer matrix elements.

Preferably, the one or more points of reference are chosen such that at these points, the difference of the minimum and maximum envelopes is not too small. The polarization parameters of the two principal states of polarization will then be determined most accurately. Another prerequisite is that the one or more points of reference are chosen such that at said points, the value of said optical property corresponds to an optical signal in the measurement that is sufficiently large. Otherwise, the impact of noise could degrade the results.

It is clear that the invention can be partly or entirely embodied or supported by one or more suitable software programs, which can be stored on or otherwise provided by any kind of data carrier, and which might be executed in or by any suitable data processing system.

BRIEF DESCRIPTION OF THE DRAWINGS

Other objects and many of the attendant advantages of the present invention will be readily appreciated and become better understood by reference to the following detailed description when considering in connection with the accompanied drawings. Features that are substantially or functionally equal or

filter used to pass only a selected wavelength range. The minimum loss 1 and the maximum loss 2 define the envelopes of the insertion loss. This means for any polarization state, the insertion loss exhibited by the device will occur within the limits defined by the minimum loss 1 and the maximum loss 2. For a certain wavelength λ_1, the polarization dependent loss (PDL) is defined as the difference 3 between the maximum loss 2 and the minimum loss 1 at the wavelength λ_1, expressed in dB. Per definition, the minimum and maximum loss curves never intersect. However, at some points, for example at point 4, the minimum loss 1 and the maximum loss 2 may be tangent to each other.

At any chosen wavelength, the maximum and the minimum loss occur at the PSP and every other state of polarization is a mixture of the PSP and thus corresponds to a loss value between those of the PSP. The polarization dependent transmission characteristics of a device under test (DUT) is not only expressed in polarization dependent loss (PDL), but also often in an apparent wavelength shift of the transmission properties. The maximum wavelength shift is observed between the two principal states of polarization of the device under test. Here, as in the product note, "PDL Measurements using the Agilent 8169A Polarization Controller", the two principal states of polarization are referred to as the J-state and the K-state to distinguish them.

Many components for fiberoptic networks are produced by defining optical waveguides, or paths for the light, in films or layers that are deposited on a flat substrate. Such components are sometimes referred to as planar lightwave circuits (PLC). The light passes along the waveguide, which lies in the plane parallel to the substrate. When this light is linearly polarized such that the electric field is perpendicular to this plane, the polarization state is usually referred to as transverse electric (TE) and when the light is polarized such that the electric field is parallel to the plane the polarization state is called transverse magnetic (TM). These TE and TM polarization states are particularly important cases for the PSPs for which it is often desired to obtain the mode spectra.

terms of wavelength, the minimum and maximum loss curves each coincide partly with the first one and the second one of the two PSPs.

For the case of a PLC, this partial coincidence of the minimum and maximum loss curves on the one hand and the TE and TM loss curves on the other hand is shown in Fig. 1C. At the intersection point 8, the TE loss curve intersects the TM loss curve. The wavelength λ_i denotes the wavelength at the intersection point 8. In the wavelength range below λ_i, the minimum loss curve 9 coincides with a first one of the TE and TM loss curves, and the maximum loss curve 10 coincides with a second one of said TE and TM loss curves. In the wavelength range above λ_i, the situation is different: Here, the minimum loss curve 11 coincides with said second one of the TE and TM curves, and the maximum loss curve 12 coincides with said first one of the TE and TM curves. Partial coincidence between the minimum/maximum loss curves on the one hand and the TE and TM curves on the other hand means that for each of the different wavelength ranges, a different assignment of the respective TE and TM modes to the minimum and maximum loss curves exists. The various wavelength ranges are delimited by the intersection points of the loss curves corresponding to the PSPs.

The partial coincidence of curves obtained for the J- and K-states of polarization on the one hand and the maximum and minimum curves on the other hand is not restricted to the case of loss measurements, though. For any optical property of a DUT, the spectral dependence of said optical property determined for the PSPs coincides either with the maximum or the minimum curve of said optical property. For this reason, the methods that will be described for obtaining optical property spectra for the J-state and the K-state of the incident light are not restricted to loss measurements of a DUT. They can also be applied to other optical properties such as reflectance, transmission, attenuation, group delay, sensitivity, etc.

In case the optical property to be determined is the insertion loss (IL) of the

emerging light wave, which can also be characterized by a Stokes vector $S_{out} = (S0_{out}, S1_{out}, S2_{out}, S3_{out})$. The matrix equation $S_{out} = M \cdot S_{in}$ represents four linear equations, but only the first one is interesting for insertion loss (IL) and PDL calculations, because $S0_{out}$ represents the total output power. From the first row of the Mueller matrix, the following equation is obtained, whereby the Mueller matrix elements m_{1k}, (k = 1, 2, 3, 4), represent the first row of the Mueller matrix:

$$S0_{out} = m_{11} \cdot S0_{in} + m_{12} \cdot S1_{in} + m_{13} \cdot S2_{in} + m_{14} \cdot S3_{in} \qquad (1)$$

The measurements with the 4 states of polarization are used to determine the m_{1k} elements. Said four different states of polarization might, for example, comprise a linear horizontal (0°) state, a linear vertical (90°) state, a linear diagonal (+45°) state, and a circular right hand state. For said four states of polarization, the optical powers $P_{a,b,c,d}(\lambda)$ input to the DUT and the optical powers $P_{1,2,3,4}(\lambda)$ emerging from the DUT are measured as a function of wavelength. All these powers can be measured with a power meter. From these measurements, the first row of the Mueller matrix comprising the matrix elements $m_{11}(\lambda)$, $m_{12}(\lambda)$, $m_{13}(\lambda)$, $m_{14}(\lambda)$ can be determined by using the algorithm based on said four different states of polarization. The algorithm below, for example, is constructed based on using a linear horizontal (0°) state, a linear vertical (90°) state, a linear diagonal (+45°) state, and a circular right hand state:

$$\begin{bmatrix} m_{11}(\lambda) \\ m_{12}(\lambda) \\ m_{13}(\lambda) \\ m_{14}(\lambda) \end{bmatrix} = \begin{bmatrix} \frac{1}{2}\left(\frac{P_1}{P_a} + \frac{P_2}{P_b}\right) \\ \frac{1}{2}\left(\frac{P_1}{P_a} - \frac{P_2}{P_b}\right) \\ \left(\frac{P_3}{P_c} - m_{11}\right) \\ \left(\frac{P_4}{P_d} - m_{11}\right) \end{bmatrix} \qquad (2)$$

assigning curve sections of the minimum and maximum loss curves between adjacent crossing points to either the J-state curve or the K-state curve. Said crossing points are identified based on the PDL curve, whereby it is supposed that the minima of the polarization dependent loss correspond to the crossing points of the two mode curves.

In Fig. 3, the interplay between the TE/TM mode curves and the PDL curve is depicted. Both insertion loss (IL) and PDL are shown in decibels (dB) as a function of wavelength. At the point 13, the minimum loss curve 14 and the maximum loss curve 15 are tangent to each other. Therefore, point 13 is one of the desired crossing points between the TE and the TM mode curves. The polarization dependent loss is defined as the difference of the minimum and the maximum loss at a certain wavelength. Ideally, the PDL value corresponding to point 13 would be zero. However, due to physical limitation of both the test equipment and the device under test, the PDL at the crossing point is non-zero, but assumes a minimum. A limit can be defined below which the PDL value of the crossing point has to fall to indicate a crossing point. Thus, the point 13 where the TE and the TM curves intersect can be identified by means of the corresponding minimum point 16 of the PDL curve 17.

In Fig. 4, the minimum and maximum loss spectra shown in Fig. 2 are shown again, together with a clear indication of the crossing points 18 obtained by analysing the PDL curve.

The following algorithm can be used for implementing the method according to the first embodiment of the invention. Starting from the maximum and minimum loss curves delivered by the Mueller method, the algorithm is capable of generating the TE and TM loss curves.

Find peak wavelength of average insertion loss
Analysis takes place within *cross band*
Whil within *cross band*
  Move to next s *arch step*
  If current λ is within *band limit* of loss peak

Identifying the crossing points of the TE and TM curves with a rather small search window works well outside of the filter's pass band. However, the PDL of an AWG tends to be low around the peak wavelength. Within the pass band, many points of the PDL curve fall below the PDL limit 23. With each search step, there would be a minimum PDL value found which might not coincide with a crossing point. Unwanted spectrum exchange might occur without limitation around the centre wavelength. This is then expressed in a sort of zig-zag in the TE and TM curves.

For this reason, a broader wavelength range covering the pass band or low PDL range must be introduced, with the PDL minimum being searched within said broader wavelength range. This wavelength range is the band limit 22 shown in Fig. 5. The band limit 22 has to be larger than the search step 21. The band limit 22 might for example be centred around the peak wavelength 19, ITU or any user defined wavelength. Alternatively, it is possible to define the band limit 22 as the wavelength range within for example 0,5 dB (or any other dB value) above the minimum loss measured at the peak wavelength 19. Within the band limit 22, the number of crossing points is limited to one crossing point. The algorithm basically comprises two steps: first, outside of the band limit 22, a scan with the search step 21 is performed in order to find the PDL minima. Then, within the low PDL area of the band limit 22, a search for the PDL minimum is performed. This search strategy is implemented by means of an if-instruction:

If current λ is within *band limit* of loss peak
   Find one minimum PDL within *band limit*
Else
   Find one minimum PDL within *search step*
end if

Next, it is checked whether the minimum PDL value found within search step 21 or within band limit 22 is a crossing point. For this purpose, the minimum PDL value is compared with a user defined PDL limit 23, and if said minimum PDL value is below said PDL limit 23, it is assumed that it corresponds to a

The second embodiment of the invention is not limited to the determination of transmission or loss properties of the DUT. Any optical property of the DUT that can be expressed as a function of such Mueller matrix elements $m_{11}(\lambda)$, $m_{12}(\lambda)$, $m_{13}(\lambda)$, $m_{14}(\lambda)$, such as absorption, reflectance, etc., can be determined.

In order to derive the insertion loss curves for the PSPs, at least one spectral point of reference is required which is used as a starting point for the calculation of the two mode curves. There are two requirements that have to be fulfilled by said point of reference. In order to be able to clearly distinguish between the different mode curves, the polarization dependent loss at said point of reference has to be sufficiently high. A second requirement is that at the wavelength corresponding to the point of reference, the signal strength of the DUT signal is sufficiently high. Therefore, the insertion loss value at said point of reference is preferably sufficiently low, for example within 3 dB from the insertion loss minimum. Since the insertion loss is an array of power over wavelength, it is possible to identify an n^{th} array element with a wavelength λ_n at said point of reference.

In a next step, the Stokes vectors of the J- and K-states of polarization are determined. One of the two Stokes vectors X_J and X_K corresponds to the insertion loss maximum at the wavelength λ_n, and the other Stokes vector corresponds to the insertion loss minimum at the wavelength λ_n. The following equations show how the two Stokes vectors X_J and X_K corresponding to the two PSPs can be expressed in terms of the matrix elements $m_{11}(\lambda_n)$, $m_{12}(\lambda_n)$, $m_{13}(\lambda_n)$, $m_{14}(\lambda_n)$ at the fixed wavelength λ_n. For the case of planar devices, the two Stokes vectors X_J and X_K correspond to the TE and TM mode.

above expression for $S0_{out}$, the transmission T can be written as

$$T = \frac{m_{11}(\lambda)\cdot S0_{in} + m_{12}(\lambda)\cdot S1_{in} + m_{13}(\lambda)\cdot S2_{in} + m_{14}(\lambda)\cdot S3_{in}}{S0_{in}} \qquad (9)$$

With $x1 = \frac{S1_{in}}{S0_{in}}$, $x2 = \frac{S2_{in}}{S0_{in}}$, $x3 = \frac{S3_{in}}{S0_{in}}$, the transmission T_J, T_K for the two principal states of polarization J, K in dependence on the wavelength λ can be written as:

$$T_J(\lambda) = m_{11}(\lambda) + m_{12}(\lambda)\cdot x1_J + m_{13}(\lambda)\cdot x2_J + m_{14}(\lambda)\cdot x3_J$$

$$T_K(\lambda) = m_{11}(\lambda) + m_{12}(\lambda)\cdot x1_K + m_{13}(\lambda)\cdot x2_K + m_{14}(\lambda)\cdot x3_K \qquad (10)$$

As described above, the states of polarization $x1_J$, $x2_J$, $x3_J$ and $x1_K$, $x2_K$, $x3_K$ have been determined at the wavelength λ_n, which is not necessarily equal to the wavelength λ at which T_J, T_K have to be determined. Here, the approximation has been made that $x1_J$, $x2_J$, $x3_J$ and $x1_K$, $x2_K$, $x3_K$ are constant within a wavelength range around λ_n. In case there is only one point of reference for the wavelength range of interest, it is even assumed that $x1_J$, $x2_J$, $x3_J$ and $x1_K$, $x2_K$, $x3_K$ are constant within the whole wavelength range of interest. The assumption that the Stokes vectors X_J, X_K corresponding to the principal states of polarization J, K do not strongly depend on wavelength is a rather good approximation, because it can be shown that there is usually only a second order dependence of the Stokes parameters X_J, X_K on the wavelength λ. This second order dependence is usually characterized as "second order polarization mode dispersion (PMD)". When the above assumption is made, the wavelength dependence of the loss curves for the J- and the K-state is generated by the wavelength dependence of the matrix elements $m_{11}(\lambda_n)$, $m_{12}(\lambda_n)$, $m_{13}(\lambda_n)$, $m_{14}(\lambda_n)$, whereby $x1_J$, $x2_J$, $x3_J$ and $x1_K$, $x2_K$, $x3_K$ are considered as constants.

It is also possible to track the spectral dependence of the polarization

polarization controller of a corresponding type is used, the parameters α_Q, α_H and 2θ have to be determined for both the J- and the K-state. Here, α_Q and α_H denote the respective angles of the controller's half wave plate and quarter wave plate, and 2θ denotes the angular displacement of a polarization state in the plane of linear polarization (θ-plane) of the Poincaré sphere. More details concerning the determination of α_Q, α_H and 2θ can be found in the appendix "A2. Calculation and Setting of Min/Max Polarization States on the 8169A" of the above-mentioned product note "PDL Measurements using the Agilent 8169A Polarization Controller".

This above-described method can also be used to obtain the PSP mode spectra of other optical properties, like for example group delay, after using the analysis of the Mueller matrix to set the instrumentation.

In Fig. 7, the calculated J- and K-state loss curves 29, 30 and the measured J- and K-state loss curves 31, 32 are shown together with the J-state calculation error 33 and the K-state calculation error 34. The system uncertainty due to external conditions, such as environmental changes and connection/disconnection of the cable, is typically about 10 mdB or above and depends on how good the fiber is maintained. Considering the above factors, the calculation error is minimum.

So far, two embodiments of the invention have been introduced for deriving the insertion loss curves for the principal states of polarization. In case of planar devices, the TE and TM mode curves are obtained. In the following, it will be described how the polarization dependent wavelength shift can be determined when said two mode curves are given.

In Fig. 8, the TE curve 35 and the TM curve 36 are shown as a function of wavelength. A first possibility for calculating the polarization dependent wavelength shift 37 is to determine the transmission maxima 38, 39 of the TE and TM curves 35, 36, and to subtract the wavelengths corresponding to said

CLAIMS:

1. A method for determining mode spectra (5, 6) of an optical property of a device under test - DUT - in dependence on a spectral parameter, with said mode spectra (5, 6) corresponding to the device's principal states of polarization - PSPs - , the method comprising the following steps:

   - determining minimum envelope values and maximum envelope values of said optical property, or other measured values from which said envelope values can be determined with respect to possible state of polarization of light that is incident upon said DUT, whereby said minimum envelope values and said maximum envelope values are determined for a spectral range of interest of said spectral parameter;

   - deriving the mode spectra (5, 6) of said optical property for at least one of the PSPs as a function of said spectral parameter for said spectral range of interest, whereby a partial correspondence of said mode spectra (5, 6) with said minimum and maximum envelope values is used for deriving said mode spectra.

2. The method according to claim 1, wherein said spectral parameter is either the wavelength or the frequency of the light incident upon said DUT.

3. The method according to claim 2, wherein, from said mode spectra, and in particular from the peaks of said mode spectra, a polarization dependent wavelength shift of the DUT is determined.

4. The method according to claim 1 or any one of the above claims, wherein said DUT is a planar lightwave circuit, such as an arrayed waveguide grating or a semiconductor optical amplifier, and wherein said mode spectra are the TE and TM mode spectra of said planar lightwave circuit.

segments of the maximum envelope and of the minimum envelope to either one of said mode spectra for the PSPs, whereby within a first of two adjacent subsections, the maximum envelope is assigned to a first mode spectrum and the minimum envelope to a second mode spectrum, and within an adjacent subsection, the maximum envelope is assigned to said second mode spectrum and the minimum envelope to said first mode spectrum.

11. The method according to claim 5 or any one of the above claims, further comprising the steps of:

- initially assigning the maximum envelope to a first mode spectrum and the minimum envelope to a second mode spectrum;

- identifying crossing points in ascending or descending order of said spectral parameter, and, for a range of said spectral parameter starting at a respective crossing point, interchanging the assignment of the tailings of said maximum and minimum envelopes to said first mode spectrum and said second mode spectrum.

12. The method according to claim 1 or any one of the above claims, comprising the steps of:

- determining at least part of a transfer matrix of the DUT, such as the Mueller matrix of the DUT, as a function of said spectral parameter;

- determining, at one or more points of reference, polarization parameters for at least one of said PSPs;

- deriving the mode spectra of said optical property in dependence on said spectral parameter from the polarization parameters at said one or more points of reference and the matrix elements of the transfer matrix, whereby said polarization parameters are assumed to be constant over spectral ranges around said points of reference,

envelope values and maximum envelope values of said optical property, or other measured values from which said envelope values can be determined with respect to possible states of polarization of light that is incident upon said DUT, whereby said minimum envelope values and said maximum envelope values are determined for a spectral range of interest of said spectral parameter;

- a mode spectra generation unit adapted for deriving the mode spectra (5, 6) of said optical property for at least one of the PSPs of said incident light as a function of said spectral parameter, which uses a partial correspondence of said mode spectra (5, 6) with said minimum and maximum envelope values for deriving said mode spectra.

18. The apparatus according to claim 17, wherein said minimum/maximum unit determines at least part of a transfer matrix of the DUT, such as the Mueller matrix of the DUT, as a function of said spectral parameter, whereby said minimum envelope values and said maximum envelope values are derived from said transfer matrix.

19. The apparatus according to claim 17 or any one of the above claims, wherein said minimum/maximum unit determines said minimum envelope values and said maximum envelope values of said optical property by varying the polarization of the incident light over various different states of polarization.

20. The apparatus according to claim 17 or any one of the above claims, wherein said mode spectra generation unit analyses where the difference between the maximum envelope and the minimum envelope is smaller than a predefined threshold, in order to identify crossing points where said mode spectra cross each other.

one or more points of reference and the matrix elements of the transfer matrix, whereby said polarization parameters are assumed to be constant over spectral ranges around said points of reference, and whereby the spectral variation of said mode spectra is generated by the dependence of said matrix elements on said spectral parameter.

25. The apparatus according to claim 24, wherein said mode spectra generation unit chooses said one or more points of reference such that at said points of reference, the minimum envelope and the maximum envelope of said optical property are sufficiently far apart to be clearly distinguishable, and that the value of said optical property is large compared to the measurement error.

26. The apparatus according to claim 17 or any one of the above claims, wherein said apparatus

- determines at least part of a transfer matrix of the DUT, such as the Mueller matrix of the DUT, as a function of said spectral parameter,
- determines, at one or more points of reference, polarization parameters for at least one of said PSPs, and
- sets the polarization state of the light from a polarization controller to the DUT according to said polarization parameters and at least part of said transfer matrix, and measures the optical property for at least one of said PSPs over a range of the spectral parameter around the respective point of reference.

ABSTRACT

The invention is related to the determination of mode spectra of an optical property of a device under test, whereby said mode spectra correspond to the device's principal states of polarization. First, measurements are made which determine minimum and maximum envelope values of said optical property with respect to possible states of polarization. From these minimum and maximum envelope values or related measured values, the mode spectra of said optical property are derived, whereby a partial correspondence of said mode spectra with said envelope values is used for assigning values of the minimum/maximum envelopes to the mode spectra. The obtained mode spectra for the principal states of polarization, which may correspond to the TE and TM states, may be used for determining the polarization dependent wavelength shift of spectral features of the device under test, which is a key parameter for PLC and AWG manufacturing processes.

(Fig. 1B for publication)

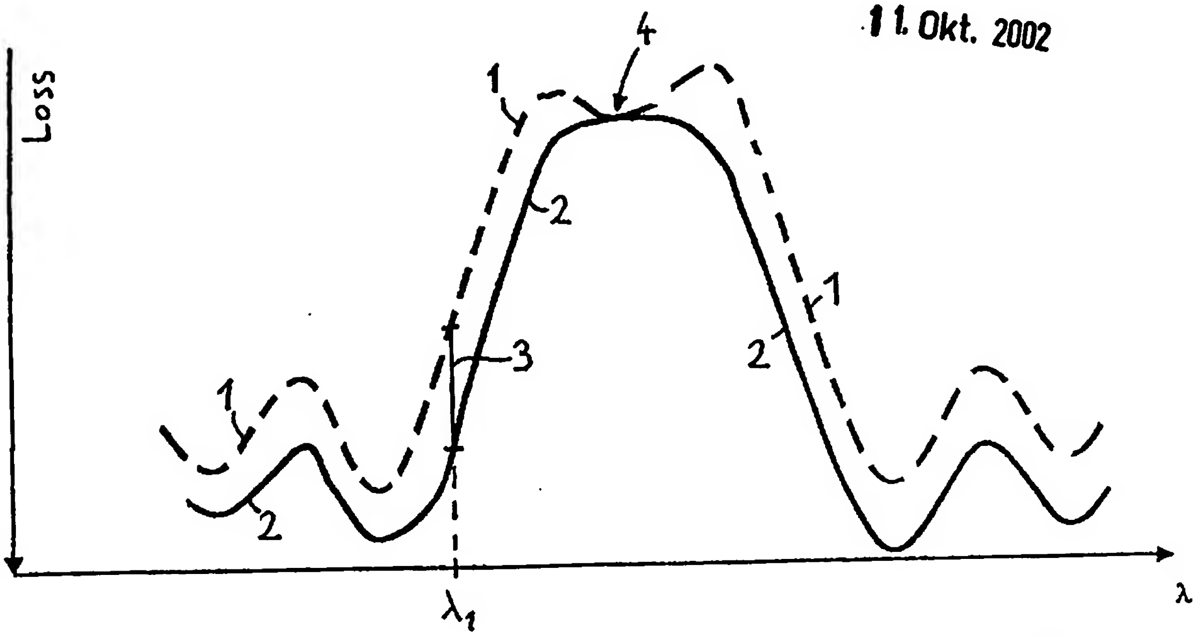

Fig. 1A

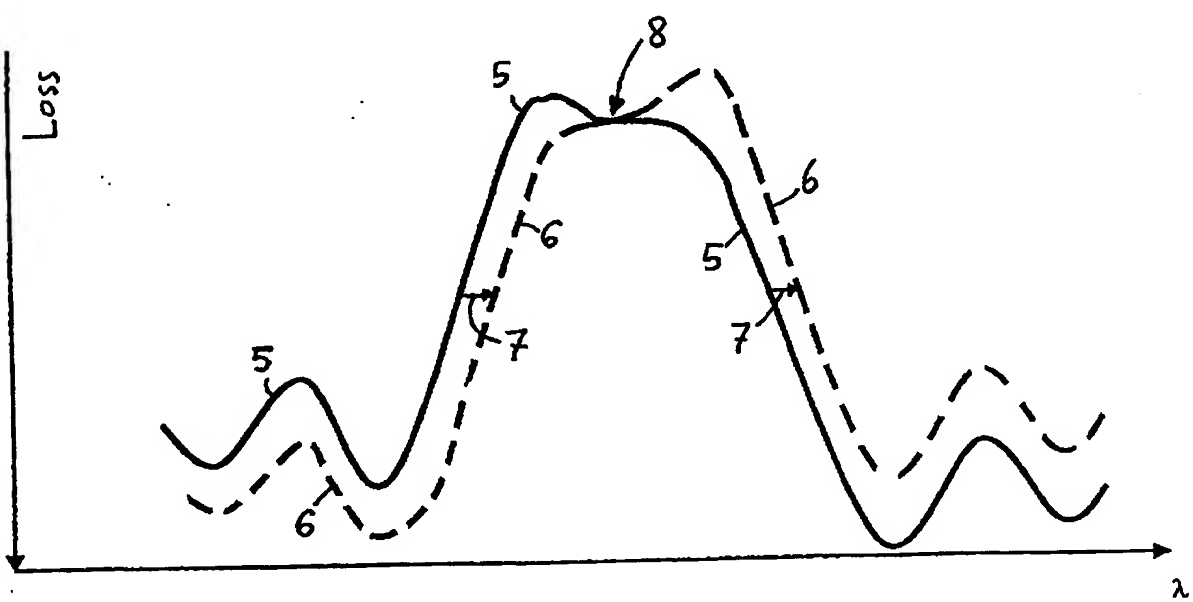

Fig. 1B

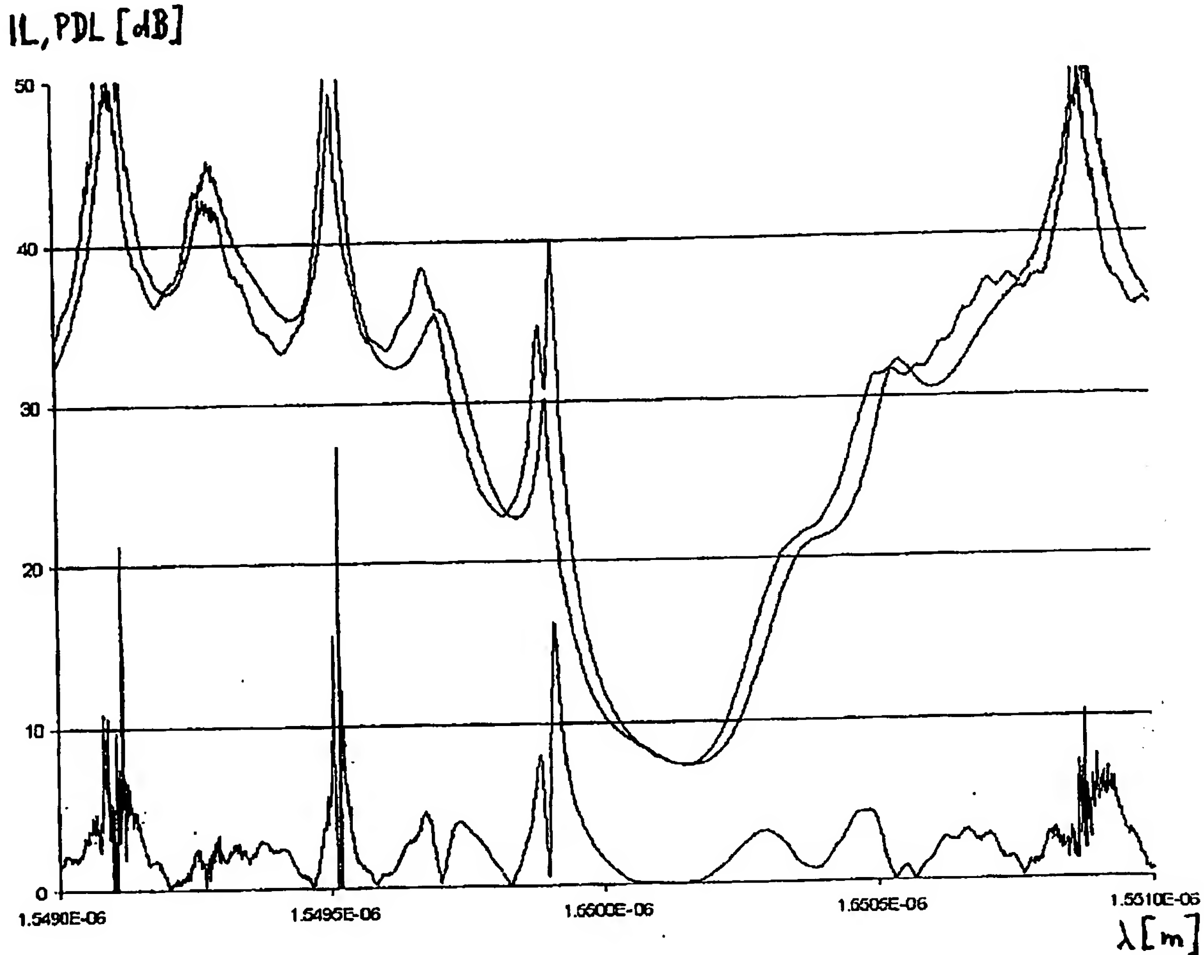
IL, PDL [dB]
50
40
30
20
10
0
1.5490E-06
1.5495E-06
1.5500E-06
1.5505E-06
1.5510E-06
λ [m]

Fig. 2

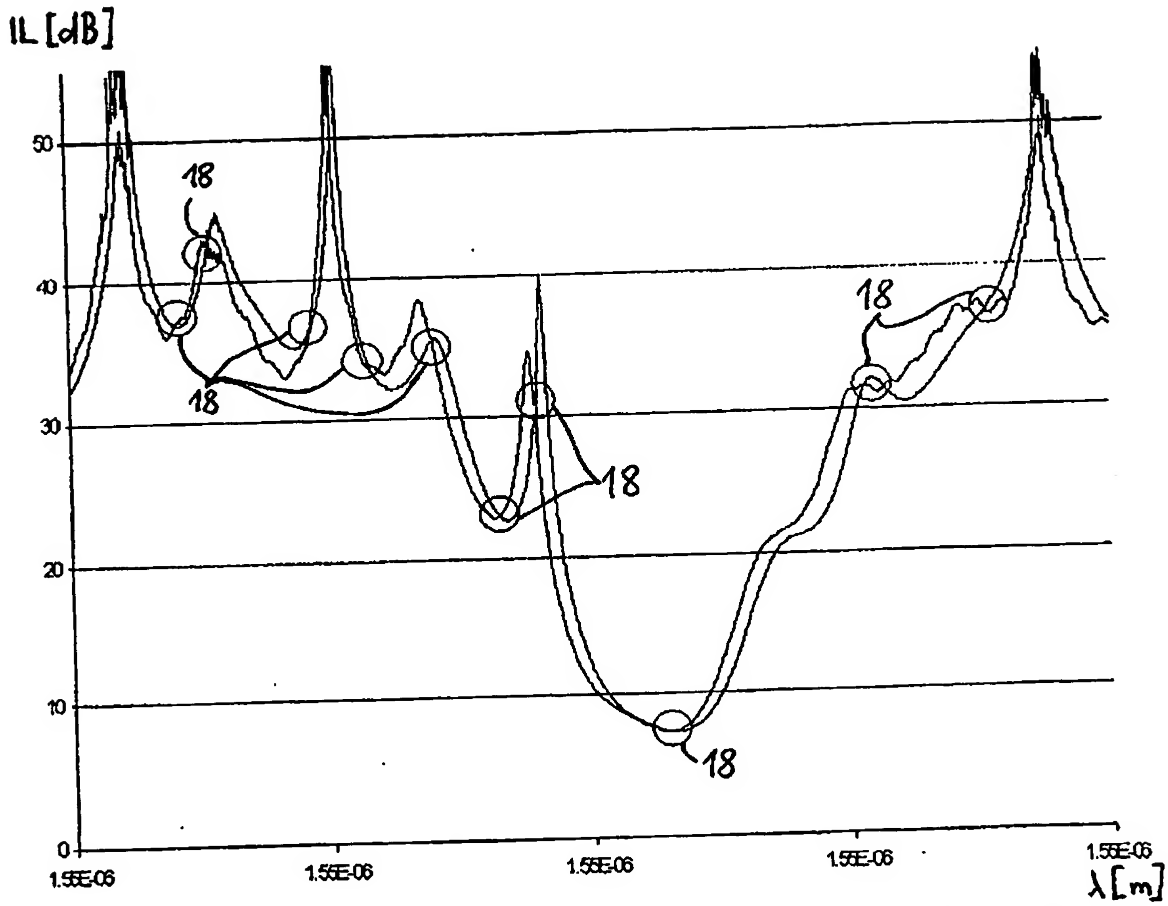
IL [dB]
50
40
30
20
10
0
18
18
18
18
18
18
1.55E-06
1.55E-06
1.55E-06
1.55E-06
1.55E-06
λ [m]

Fig. 4

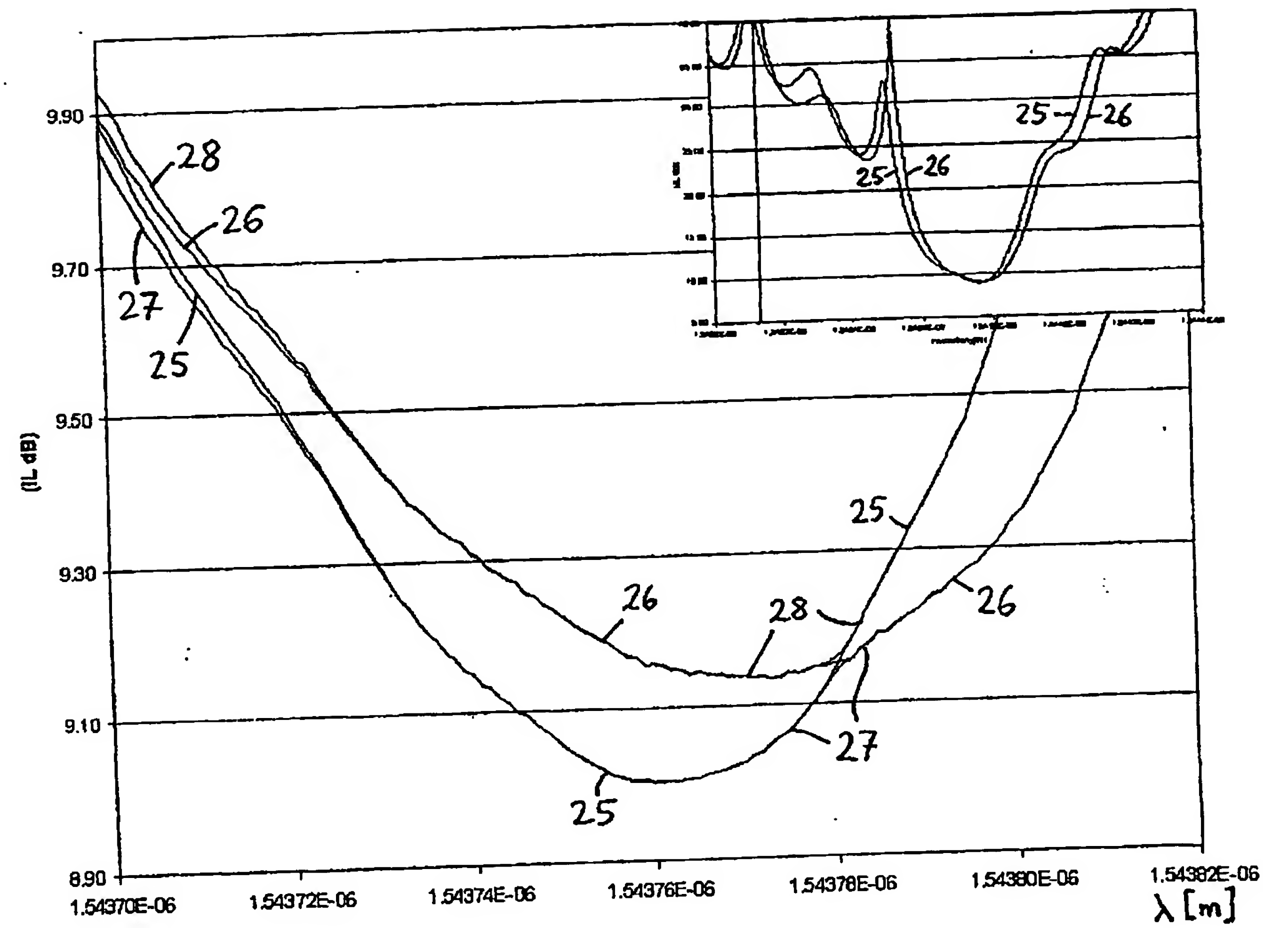
9.90
9.70
9.50
9.30
9.10
8.90
(IL dB)
1.54370E-06
1.54372E-06
1.54374E-06
1.54376E-06
1.54378E-06
1.54380E-06
1.54382E-06
λ [m]
28
26
27
25
25
26
28
26
27
25
25
26
25
26

Fig. 6

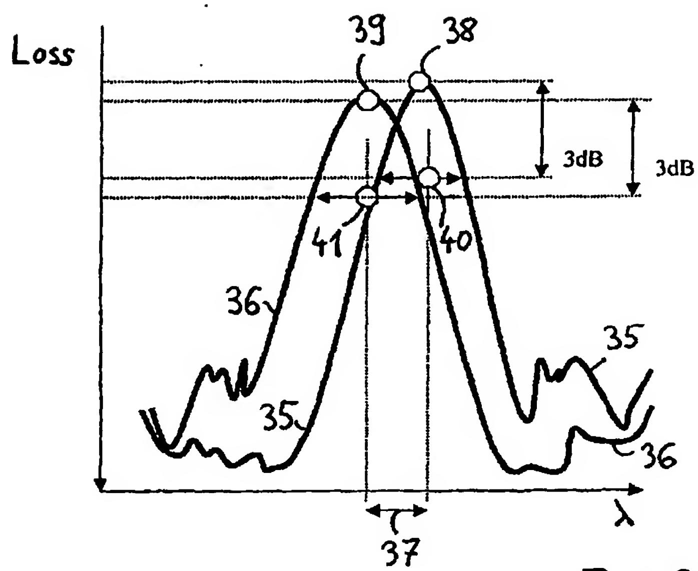

Fig. 8